30th Electrical Engineering Conference

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**PW3-2**

วันพฤหัสบดีที่ 25 ตุลาคม 2550 เวลา 14:50 น. – 16:50 น.

**ห้อง:** Emerald

**ประธานกลุ่มฝ่าย:** ดร. บุญชู ปลีกกลาง มหาวิทยาลัยเทคโนโลยีราชมงคลธัญบุรี

**Title:** Transmission Pricing for Enhanced Single Buyer Model in the Thai Electricity Supply Industry

**Abstract:**

"This paper proposes a transmission pricing for the Enhanced Single Buyer model in the Thai Electricity Supply Industry. The transmission pricing comprises three components; Transmission Use-of-System charge (TUoS), connection charge, and common service charge. The original TUoS charge is a uniform tariff for each voltage level. It does not send incentive signal to the transmission users depending on system usage and congestion. The sensitivity method is proposed to deliver the incentive signal to the users by multiplying the original TUoS tariff with the nodal sensitivity index for each connecting point. Both active and reactive power are taken into consideration by analyzing MVA-flow via the transmission lines. The 424-bus power system demonstrates the method exemplarily."

**PW3-3**

**Title:** Distributed Slack Bus Power Flow Part II: Prospect and Challenge for Competitive Environments

**Abstract:**

"This paper introduces an application of distributed slack bus power flow to competitive electricity supply industry (ESI). The participation factors of the generators are obtained by the weighted average of AGC accepted quantities in the ancillary services market. The results shows that the proposed method can satisfactory represent the system behavior that all generators are response to power imbalance. In addition, the proposed method results in the better justified AGC setting in competitive electricity market than that of using single slack bus power flow."

**PW3-4**

**Title:** An Investigation Study on Fuzzy Line Flow Limit Constraints in Competitive Electricity Markets

**Abstract:**

"In this paper, the fuzzy set theory is applied to model the soft constraint limits. The fuzzy constrained optimal dispatch is formulated as a fuzzy optimization problem and converted into a crisp optimization problem. An efficient successive linear programming method is then modified to solve the new problem. Numerical test results on IEEE 30-bus system show that the fuzzy constrained method could give a good trade-off between reducing generation cost and satisfying constraints, and produce more realistic generation schedules when a feasible solution cannot be obtained by using the crisp OPF."

**PW3-5**

**Title:** Distributed Slack Bus Power Flow Part I: Mathematical Model and Framework

**Abstract:**

"This paper presents the mathematical model and test example of distributed slack bus power flow (DSPF) program. The method can diversify the power imbalance to voltage controlled buses in the system via participation factor. Therefore, the automatic generation controls (AGC) of the generators can be incorporated in this power flow model. The DSPF is tested with the IEEE 30 bus system. Numerical results shown that the method can effectively represent the generation control characteristics to the power flow model and potentially be applied to the overcoming competitive electricity supply industry."

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การประชุมวิชาการทางวิศวกรรมไฟฟ้า ครั้งที่ 30 (EECON-30) 25-26 ตุลาคม 2550 มหาวิทยาลัยเทคโนโลยีราชมงคลธัญบุรี 14
การประชุมวิชาการทางวิศวกรรมไฟฟ้าครั้งที่ 30 (EECON-30) 25-26 สิงหาคม 2550 มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี
An Investigation Study on Fuzzy Line Flow Limit Constraints in Competitive Electricity Markets

Keerati Chayakultheeree, Kasidaj Tipumpornwivat, Ekarat Fluno, Chaitirat Wisutirat, and Paradon Raungkool

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Abstract

In this paper, the fuzzy set theory is applied to model the soft constraint limits. The fuzzy constrained optimal dispatch is formulated as a fuzzy optimization problem and converted into a crisp optimization problem. An efficient successive linear programming method is then modified to solve the new problem. Numerical test results on IEEE 30-bus system show that the fuzzy constrained method could give a good trade-off between reducing generation cost and satisfying constraints, and produce more realistic generation schedules when a feasible solution cannot be obtained by using the crisp OFF.

Keywords: Optimal Power Dispatch, Competitive electricity market, Fuzzy Linear Programming

1. Introduction

In deregulated power systems, one of the main challenges to the independent system operator (ISO) is to matching supply and demand in an optimal and secure manner. That is, ISO must hold an available aggregate generating supply enough to meet the required consumer demand under the generating and system constraints, and capable of responding quickly to changes in load in real time.

Many techniques have been developed over the years to formulate and solve the optimal power dispatch for electricity markets. Linear programming (LP) is one of most successful techniques that has been applied to determine generation dispatch under this price based environment. For example, Faiz et al. [1] presented an application of LP to maximize the savings of interchange schedule to each utility participants in energy brokerage system. Rau [2] formulated and solved the optimal dispatch problem as a mixed integer linear program to buy/sell electricity and ancillary services. The line flow limits were neglected to simplify the problem. However, such constraint can not be ignored in the real practical system.

To incorporate line limit constraint, an optimal dispatch problem can be formulated as an extended problem in the conventional optimal power flow (OPF) which involves the determination of the instantaneous optimal steady state of an electric power system. Different classes of the OPF problem, tailored towards special-purpose applications, are defined by selecting different functions to be optimized, different sets of controls, and different sets of constraints. Different solution approaches have been developed to solve the different classes of the OPF problem, linear programming, successive quadratic programming, successive separable programming, Newton’s method and the interior point method. Most of the proposed methods that have been developed over the last ten years are based on real and reactive de-coupling.

However, a serious drawback in OPF is the crisp treatment of the constraints. Constraint limits are given fixed values that have to be met at all times. Crisp treatment of the constraints in the OPF problem usually leads to over-conservative solutions. Also, when crisp constraints are not satisfied in the conventional mathematical programming, it is difficult to learn what kinds of constraints are critical to what extent. Realistic OPF solutions require special attention to the constraint enforcement and control action curtailment. From a practical point of view, an OPF does not need to find a rigid minimum solution. Certain trade-off among objective function and constraints would be desirable.

The constraints of a real-life system, in terms of physical realizability, can be divided into two groups including physical limits of controls and operating limits. Physical limits on the control variables cannot be violated. However, operating limits are imposed to enhance security and do not represent physical bounds. They can be relaxed temporarily, if necessary. For example, if the limit for each transmission line is classified into two types as normal and emergency limits, in general, operators desire to economically operate the system within the normal limits. The fuzzy set theory is a natural and appropriate tool to represent imexact relation. Based on the fuzzy set theory, an OPF problem can be modified to include fuzzy constraints and fuzzy objective functions. The problem can then be converted to a crisp optimization problem, which can be solved by conventional mathematical programming approaches.

These developments have made it possible to use this technology to overcome some of the limitations of the conventional OPF.

constraints in OPF. The model formulated for system cost minimization the vertically integrated ESI. W.H. Edwin Liu and X.Guan [7] apply a fuzzy set method to efficiently model the fuzzy constraint limits (line flow) and control action curtailment in OPF. Similarly, the model formulated for system cost minimization the vertically integrated ESI.

In this study, the fuzzy set theory is applied to model the soft constraint limits. The fuzzy constrained optimal dispatch is formulated as a fuzzy optimization problem and converted into a crisp optimization problem. An efficient successive linear programming method is then modified to solve the new problem. Numerical test results on IEEE 30-bus system show that the fuzzy constrained method could give a good trade-off between reducing generation cost and satisfying constraints, and produce more realistic generation schedules when a feasible solution cannot be obtained by using the crisp OPF.

2. Fuzzy Line Flow Limit Constraint in Electricity Market

The objective functions for optimal power dispatch in electricity market can be expressed as,

Minimize \[ \sum_{i=1}^{NG} \sum_{j=1}^{NC} \sum_{t=1}^{NB} \delta_{ijt} P_{ijt}, \]  

in a single bidding (non demand side bidding, DSB) market.

Subject to the power balance constraints,

\[ P_{ct} - P_{dt} = \sum_{j=1}^{NG} \sum_{t=1}^{NB} \delta_{ijt} P_{ijt} \cos(\delta_{ijt} - \delta_{ct}), \quad i = 1, \ldots, NG \]

\[ Q_{ct} - Q_{dt} = \sum_{j=1}^{NG} \sum_{t=1}^{NB} \delta_{ijt} P_{ijt} \sin(\delta_{ijt} - \delta_{ct}), \quad i = 1, \ldots, NG \]

where,

\[ P_{ct} = \sum_{j=1}^{NG} P_{ijt}, \quad \text{for } i = 1, \ldots, NG \]

\[ 0 \leq P_{ijt} \leq P_{ijt}^{\text{max}}, \quad \text{for } j = 1, \ldots, NS_j \]

and the linearized line flow limit constraints which are treated as soft constraints,

\[ f_i = f_i + \sum_{j=1}^{NG} (P_{ijt} - P_{ijt}^{\text{max}})^2 f_i^{\text{max}}, \quad \text{for } i = 1, \ldots, NC \]

where,

\[ f_i^{\text{max}} = \sqrt{\text{line MVA limit}^2 - \text{line MVAR limit}^2}, \]

\[ a_i = \frac{df_i}{df_j}, \]

where,

\[ f_i \]  is MVA flow of line or transformer \( i \) (MVA), \n
\[ f_i^{\text{max}} \]  is MVA flow limit of line or transformer \( i \) (MVA), \n
\[ NC \]  is total number of lines, \n
\[ NB \]  is total number of buses.

\[ NG \]  is total number of buses connected to generators,

\[ NS_j \]  is number of segments of generator supply cost function at bus \( i \),

\[ P_{ijt}^{\text{max}} \]  is generator offer block \( j \) at bus \( i \) (MW),

\[ P_{ijt}^{\text{max}} \]  is maximum real power generation at bus \( i \) (MW),

\[ P_{ijt}^{\text{max}} \]  is minimum real power generation at bus \( i \) (MW),

\[ P_{ijt}^{\text{max}} \]  is total real power demand at bus \( i \) (MW),

\[ P_{ijt}^{\text{max}} \]  is real power generation at bus \( i \) (MW),

\[ P_{ijt}^{\text{max}} \]  is accepted generator offer block \( j \) at bus \( i \) (MW),

\[ P_{ijt}^{\text{max}} \]  is total system real power loss (MW),

\[ P_{ijt}^{\text{max}} \]  is reactive power voltage controlled generation at bus \( i \) (MVAR),

\[ P_{ijt}^{\text{max}} \]  is reactive power demand at bus \( i \) (MVAR),

\[ P_{ijt}^{\text{max}} \]  is offer price block \( j \) of generator at bus \( i \) ($/MWh),

\[ \delta_{ijt} \]  is magnitude of the \( \delta \) element of \( \Gamma_{ijt} \) (mho),

\[ Z_i \]  is committed or uncommitted status of generator at bus \( i \),

\[ \delta_{ij} \]  is angle of the \( \delta \) element of \( \Gamma_{ijt} \) (radian), and

\[ \delta_{ijt} \]  is voltage angle difference between bus \( i \) and \( j \) (radian).

In the fuzzy line constraints OPD formulation, the limit constraint in Eq (7) is treated as fuzzy constraint as shown in Fig 1. The membership function of the objective is obtained by defining the solution space from the worst case value (when the limit constraint is violated) and the best value (when the limit constraints are treated at its emergency operating limits).

![Fig 1 The fuzzy membership function of the line limit constraint](image)

Accordingly, the steady state continuous operating limit can be temporarily violated. However, the emergency operating limit can never be violated. The membership function of the objective function in the single and double side electricity markets are shown in...
Fig. 2. Table 1. shows the example data of transmission lines and transformer limits taken from the IEEE reliability test system 1996 (RTS-96).

Fig. 2. The fuzzy membership function of the objective functions of Single side bidding electricity market

Table 1. Typical transmission lines and transformer limits (IEEE RTS-96)

<table>
<thead>
<tr>
<th>Transmission Line</th>
<th>Continuous rating (MVA)</th>
<th>Long-time emergency rating (24 hr)</th>
<th>Short-time emergency rating (1 hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>175 (100%)</td>
<td>195 (-110%)</td>
<td>200 (-115%)</td>
<td></td>
</tr>
<tr>
<td>175 (100%)</td>
<td>208 (-120%)</td>
<td>220 (-125%)</td>
<td></td>
</tr>
<tr>
<td>500 (100%)</td>
<td>600 (120%)</td>
<td>625 (125%)</td>
<td></td>
</tr>
<tr>
<td>Transformer</td>
<td>400 (100%)</td>
<td>510 (-125%)</td>
<td>600 (-150%)</td>
</tr>
<tr>
<td>722 (100%)</td>
<td>895 (-120%)</td>
<td>891 (-120%)</td>
<td></td>
</tr>
</tbody>
</table>

Since we try to optimize the objective function while satisfying the constraints, the optimal solution in the fuzzy environment is defined as the intersection of the fuzzy sets describing the constraints and objective. So, the overall membership function value is considered as,

\[ \lambda = \min[\mu_{obj}, \mu_1, \mu_2, \ldots, \mu_{NC}] \]  

The higher the membership values the better the solution. Thus, the best solution is,

\[ \max_\lambda = \max \min[\mu_{obj}, \mu_1, \mu_2, \ldots, \mu_{NC}] \]  

Where

- \( \lambda \) is the overall membership function of the result.
- \( \mu_{obj} \) is the membership function of the fuzzy objective function.
- \( \mu_i \) is the membership function of the fuzzy line flow constraint of line \( i \).

The overall computational procedure can be expressed as in Fig. 3.

3. Numerical Results

The test data are obtained from the optimal power flow analysis data on the modified IEEE 30-bus system. Its network diagram is shown in [8] with the line 11-9 limit set to 60 and 50 MVA instead of 65 MVA. The dispatch result is shown in Table 2. The line 9-11 flow is violate its limit and resulted in binding solution on the line 11-9 flow limit constraint.

Fig. 4 The Generator’s offers of IEEE 30 bus system

Fig 5 Dispatch results when line 11-9 limit 60 MVA with Crisp Constrained Optimal Power Dispatch (LP)

Table 2 Total cost and flow of congested line (11-9) without demand side bidding

<table>
<thead>
<tr>
<th>Line 11-9 limit (MVA)</th>
<th>Linear Programming</th>
<th>Fuzzy Linear Programming</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Line 11-9 flow (MVA)</td>
<td>Total Cost ($/hr)</td>
</tr>
<tr>
<td>60</td>
<td>60.000</td>
<td>4.741.060</td>
</tr>
<tr>
<td>50</td>
<td>50.000</td>
<td>4.854.598</td>
</tr>
</tbody>
</table>
4. Conclusions

In this paper, the benefit from soft characteristics of transmission line and transformer limit constraints can be acquired in the fuzzy constrained optimal power dispatch problem. The fuzzy linear programming is applied for solving the soft characteristics of transmission line and transformer limit constraints by trading-off between the objective and constraints in a fuzzy reasoning sense. The experimental results show the higher social welfare and lower total generating cost in the electricity market, when the transmission line and transformer limit constraints are treated as fuzzy constraints in the dispatch problem.

References